A HEAT TRANSFER TUBE
AND A METHOD OF FABRICATION THEREOF

FIELD OF THE INVENTION

[0001]   The invention relates to a metallic heat transfer tube, in particular for the evaporation of liquids from pure substances or mixtures on the outside of the tube.

BACKGROUND OF THE INVENTION

[0002]   Evaporation occurs in many areas of air conditioning and refrigeration engineering and in process and energy engineering. Shell and tube heat exchangers are often used in this type of engineering, in which exchangers liquids from pure substances or mixtures evaporate on the outside of the tube, and thereby cool off a brine or water on the inside of the tube. Such devices are identified as flooded evaporators.

[0003]   By intensifying the heat transfer on the outside and the inside of the tube, it is possible to significantly reduce the size of the evaporator. This reduces the manufacturing costs of such devices. Furthermore the required filling capacity of refrigerant is reduced which, in the case of the current predominantly used HFCs, can amount to a significant portion of the entire cost of the system. Furthermore, the potential of danger can be reduced, in the case of toxic or flammable refrigerants, by a reduction of the filling capacity. The current common double enhanced tubes are more efficient by approximately a factor of three than plain tubes with the same diameter.

STATE OF THE ART

[0004]   The present invention relates to structured tubes in which the heat transfer coefficient is intensified on the outside of the tube. Since the main portion of the heat transfer resistance is in this manner

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often shifted to the inside, the heat transfer coefficient must as a rule also be intensified on the inside. An increase of the heat transfer on the inside of the tube results usually in an increase of the tubeside pressure drop.

[0005]   Heat transfer tubes for shell and tube heat exchangers have usually at least one structured area and one plain end and possibly plain center lands. The plain ends or center lands provide the limits of the structured areas. In order for the tube to be able to be installed without any problems into the shell and tube heat exchanger, the outer diameter of the structured areas may not be greater than the outer diameter of the plain ends and center lands.

[0006]   In order to increase the heat transfer during the evaporation, the process of the nucleate boiling is intensified. It is known that the formation of bubbles starts at the nucleation sites. These nucleation sites are mostly small gas or vapor inclusions. Such nucleation sites can be produced already by roughening the surface. When the growing bubble has reached a certain size, it becomes detached from the surface. When the bubble becomes detached, the nucleation site is flooded with liquid and any included gas or vapor may also be displaced by the flooding liquid. The nucleation site is in this case inactivated. This can be avoided by a suitable design of the nucleation sites. It is here necessary to make the opening of the nucleation site smaller than the cavity lying below the opening.

[0007]   It is known in the art to produce such structures on the base of integrally formed finned tubes. Integrally finned tubes are where the fins are formed out of the wall material of a plain tube. Various methods are known whereby the channels between adjacent fins are closed off in such a manner that connections between

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channel and surrounding area remain in the form of pores
or slots. Since the opening of the pores or slots is
less than the width of the channels, the channels
represent suitably formed cavities, which favor the
formation and stabilization of nucleation sites. Such
essentially closed channels are created in particular by
bending or tilting the fin (US 3 696 861, US 5 054 548),
by splitting and flattening the fin (DE 2 758 526,
US 4 577 381), and by notching and flattening the fin
(US 4 660 630, EP 0 713 072, US 4 216 826).

[0008]   The strongest commercially available
performance enhanced fin tubes for flooded evaporators
have a fin structure with a fin density of 55 to 60 fins
per inch on the outside of the tube (US 5 669 441,
US 5 697 430, DE 197 57 526). This corresponds to a fin
pitch of approximately 0.45 to 0.40 mm. It is
principally possible to improve the performance of such
tubes with a yet higher fin density or smaller fin pitch
since this increases the nucleation site density. A
smaller fin pitch requires automatically more delicate
tools. However, more delicate tools are subjected to an
increased danger of breakage and quicker wear. The
presently available tools enable a safe manufacture of
finned tubes with fin densities of 60 fins per inch at a
maximum. Furthermore a decreasing fin pitch reduces the
production speed of the tubes and consequently the
manufacturing costs are increased.

[0009]   It is known that performance-enhanced
evaporation structures without changing the fin density
can be produced on the outside of the tube by structuring
the base of the groove between the fins. It is suggested
in EP 0 222 100 to provide the base of the groove with
indentations by means of a notching disk. The
indentations at the base of the groove can have a V,
trapezoidal or semicircular cross section and represent

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additional nucleation sites. However, the performance increases achievable by such structures in particular in the range of small heat fluxes no longer meet the demands of the market. The indentations represent furthermore a weakening of the core wall of the tube and result in a reduction of the mechanical stability of the tube.

PURPOSE OF THE INVENTION

[0010]   A performance-enhanced heat transfer tube for the evaporation of liquids on the outside of the tube is to be provided during a uniform tubeside heat transfer and pressure drop and with the same manufacturing costs.

SUMMARY OF THE INVENTION

[0011]   The purpose of the invention is met by providing in a heat transfer tube of the mentioned type, recesses which are arranged in the area of the base of the primary grooves helically extending between the fins, in such a manner that the recesses are designed in the form of re-entrant secondary grooves.

[0012]   A re-entrant groove (see Figure 1) exists when
  · in a sectional plane a not closed off
     field X can be found;
  · the field X can be closed off by means of a
     region AB;
  · a region PQ, with P, Q being part of a boundary of
     X, is found so that PQ is parallel to AB and the
     width of PQ is greater than the width of AB.

[0013]   A re-entrant secondary groove offers for the formation and stabilization of nucleation sites clearly more favorable conditions than the simple indentations suggested in EP 0 222 100. The position of the re-entrant secondary grooves near the primary base of the groove is particularly advantageous for the evaporation process since the wall superheat is the greatest at the base of the groove and therefore the highest driving

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temperature difference for the bubble formation is available thereat.

[0014]   After the forming of the fins material is according to the invention removed by suitable additional tools, from the area of the fin flanks toward the base of the groove so that not completely closed off cavities are created at the base of the groove, which cavities define the desired re-entrant secondary grooves. The cavities extend from the base of the primary groove toward the tip of the fins, whereby the cavities expand at a maximum up to 45% of the fin height H, typically up to 20% of the fin height H. The fin height H is thereby measured from the lowermost portion of the base of the groove, which was formed by the largest rolling disk, to the fin tip of the completely formed finned tube.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]   The invention will be discussed in greater detail hereinafter in connection with reference to the accompanying drawings, in which:

[0016]   Figure 1 is the principle sketch of a re-entrant groove;

[0017]   Figure 2 illustrates schematically the manufacture of a heat transfer tube of the invention with re-entrant secondary grooves, which extend helically with an essentially constant cross section on the outside of the tube;

[0018]   Figure 3 is a partial view of a heat transfer tube of the invention with re-entrant secondary grooves, which extend helically with an essentially constant cross section;

[0019]   Figure 4 illustrates schematically the manufacture of a heat transfer tube of the invention with helically extending, re-entrant secondary grooves, the cross section of which is varied at regular intervals;

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[0020]   Figure 5 is a partial view of a heat transfer tube of the invention with helically extending, re-entrant secondary grooves, the cross section of which is varied at regular intervals;

[0021]   Figure 6 illustrates schematically the manufacture of a heat transfer tube of the invention with re-entrant secondary grooves, which extend essentially transversely to the direction of the primary grooves;

[0022]   Figure 7 is a partial view of a heat transfer tube of the invention with re-entrant secondary grooves, which extend essentially transversely with respect to the direction of the primary grooves;

[0023]   Figure 8 is the photo of a re-entrant secondary groove of the invention at the base of the groove, which groove extends helically with an essentially constant cross section;

[0024]   Figure 9 is a diagram, which documents the performance advantage by the re-entrant secondary groove at the base of the groove.

DETAILED DESCRIPTION

[0025]   An integrally rolled finned tube 1 according to Figures 2 to 7 has fins 3 extending helically on the outside of the tube, between which fins a primary groove 4 is formed. Material of the fin flanks 5 is suitably shifted so that cavities 7, which are not completely closed off, are created in the area of a base 6 of each of the primary grooves 4, which cavities represent the re-entrant secondary grooves of the invention. Material of the fin tips 8 is shifted in such a manner that the spaces between the fins are closed off to thereby form channels 9 externally accessible through radially open pores 26.

[0026]   The finned tube of the invention is manufactured through a finning process (compare

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US 1 865 575, US 3 327 512) by means of the devices
illustrated in Figures 2, 4 and 6.

[0027]   A device is utilized, which consists of n = 3
or 4 arbors 10, onto each of which a rolling tool 11 is
integrated. The arbors 10 are circumferentially offset
at 360°/n on the periphery of the finned tube. The
arbors 10 can be moved radially. They in turn are
arranged in a stationary (not illustrated) milling head.

[0028]   The plain tube 2 entering the device in
direction of the arrow in Figures 2, 4 and 6 is rotated
by the peripherally arranged rotating rolling tools 11.
The axes of the rolling tools 11 extend in a skewed
relation to the tube axis. The rolling tools 11 consist
in a conventional manner of several side-by-side arranged
rolling disks 12, the diameter of which increases in the
direction of the arrow. The centrally arranged rolling
tools 11 form the helically extending fins 3 out of the
tube wall of the plain tube 2. The tube wall is supported
in the shaping zone by a mandrel 27. The mandrel 27 can
be profiled. The distance between the centers of two
adjacent fins, which distance is measured lengthwise with
respect to the tube axis, is identified as the fin pitch
T. The rolling disks are profiled on their outer
periphery in such a manner that the formed fins 3 have an
essentially trapezoidal cross section. The fin deviates
from the ideal trapezoidal shape only in the transition
area 13 between fin flank 5 and the base 6 of the groove.
This transition area 13 is usually identified as root of
the fin. The there formed radius is needed in order to
enable an unobstructed material flow during formation of
the fins.

[0029]   After the essentially trapezoidally shaped fins
3 have been formed by the rolling tool 11, the re-entrant
secondary grooves 7 of the invention are created in the

area of the base 6 of the primary grooves 4. Three
different tool embodiments can be used for this purpose:
Embodiment 1 (Figure 2):

[0030]   A cylindrical disk 14 is provided immediately
after the last disk 12 of the rolling tool 11. The
diameter of the disk 14 is less than the diameter of the
largest rolling disk 12. The thickness D of the
cylindrical disk 14 is slightly greater than the width B
of the primary groove 4 formed by the rolling disks 12,
the width B of the primary groove 4 being measured at the
point where the fin flank 5 transfers over into the
radius area of the root of the fin 13. The thickness D
of the cylindrical disk is typically 50% to 80% of the
fin pitch T. The cylindrical disk 14 removes material
from the fin flanks 5 and effects a movement thereof
toward the base 6 of the primary groove 4. The removed
material is shifted by suitably selecting the tool
geometry in such a manner that it forms projections 15
(Figure 3) above the base 6 of the primary groove 4 and
thus a radially open closed off cavity 7 is formed
directly at the base 6 of the primary groove 4. This
cavity 7 extends in circumferential direction and has a
predominately uniform cross section. The cavity 7
defines the heretofore mentioned re-entrant secondary
groove of the invention.

[0031]   It is advantageous to provide on the radially
outer surface of the disk 14 a concave profile (not
shown), either continuous or in spaced arcuate segments
in order to facilitate the removal of the material of the
fin side 5.

[0032]   Since the diameter of the cylindrical disk 14
is less than the diameter of the largest rolling disk 12
of the rolling tool 11, the lowermost portion of the base
6 of the primary groove 4 is not worked by the
cylindrical disk 14. The tube wall 18 is thus not

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weakened during the forming of the re-entrant secondary grooves 7.

Embodiment 2 (Figure 4):

[0033]   This embodiment represents an expansion of Embodiment 1. That is, a gear-like notching disk 16 is provided immediately after the cylindrical disk 14. The diameter of the notching disk 16 is greater than the diameter of the cylindrical disk 14, however, at most as great as the diameter of the largest rolling disk 12 of the rolling tool 11. The cavity 7 formed by the cylindrical disk 14 and extending in circumferential direction and having a uniform cross section is partitioned by indentations 17 (Figure 5) formed in the radially outer roof thereof by the notching tool 16 at regular intervals in the circumferential direction. Thus, the heretofore uniform cross section of the circumferentially extending re-entrant secondary grooves 7 is now varied at regular intervals. The notching disk 16 can be straight or helically toothed.

[0034]   Since the diameter of the gear-like notching disk 16 is not greater than the diameter of the largest rolling disk 12 of the rolling tool 11, the lowermost portion of the base 6 of the primary groove 4 is not farther recessed by the gear-like notching disk 16. The tube wall 18 is thus not weakened during the forming of the re-entrant secondary grooves 7 according to Embodiment 2.

Embodiment 3 (Figure 6):

[0035]   A gear-like notching disk 19 is provided immediately after the last disk 12 of the rolling tool 11. The diameter of the notching disk 19 is at most as great as the diameter of the largest rolling disk 12. The thickness D' of the notching disk 19 is slightly greater than the width B of the primary groove 4 formed by the rolling disks 12, the width B of the primary

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groove 4 being measured at the point where the fin flank 5 transfers over into the radiused portion of the root of the fin 13. The thickness D' of the notching disk is typically 50% to 80% of the fin pitch T. The notching disk 19 can be straight or helically toothed. The notching disk 19 removes material from the area of the fin flanks 5 and from the radiused portion of the root of the fin 13 to thereby form spaced-apart indentations 20 (Figure 7). The removed material is preferably shifted into the not worked area between the individual indentations 20 so that coined dams 21 are formed on the base 6 of the primary groove 4. The dams 21 extend transversally to the circumferentially extending primary grooves 4 and between the mutually adjacent fins 3. A next following finishing rolling disk 22 of a uniform diameter deforms the upper areas of the dams 21 to cause material movement in direction of the tube circumference so that small cavities 7 are formed between two mutually adjacent dams 21 and between the deformed upper area 23 of the dams 21 and the base 6 of the groove (Figure 7). These cavities 7 are the heretofore mentioned re-entrant secondary grooves of the invention. The diameter of the finishing rolling disk 22 must be chosen to be less than the diameter of the notching disk 19 working the base of the grooves.

[0036] Since the diameter of the gear-like notching disk 19 is not greater than the diameter of the largest rolling disk 12 of the rolling tool 11, the lowermost portion of the base 6 of the primary groove 4 is not farther recessed by the gear-like notching disk 19. The tube wall 18 is thus not weakened during the forming of the re-entrant secondary grooves 7 according to the Embodiment 3.

[0037] After the re-entrant secondary grooves 7 have been formed at the base 6 of the groove, the fin tips 8

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are notched by means of a gear-like notching disk 24.
The notching disk 24 is also illustrated in Figures 2 and
4, as well as in 6. A flattening of the notched fin tips
subsequently occurs caused by one or several flattening
disks 25. The fins 3 thus become formed into an
essentially T-shaped cross section, and the grooves 9
formed between the fins 3 are closed off but for the
radially open pores 26 (see Figures 3, 5 and 7).

[0038]   The fin height H is measured at the finished
fin tube 1 from the lowermost portion of the base 6 of
the groove to the tip of the fin of the completely formed
fin tube.

[0039]   The re-entrant secondary grooves 7 of the
invention at the base 6 of the primary grooves 4 extend
from the base 6 of the groove toward the fin tip. The
cavities 7 expand at a maximum to 45% of the fin height
H, typically to 20% of the fin height H.

[0040]   Figure 8 shows a photo of a re-entrant
secondary groove 7 of the invention at the base 6 of the
groove. The sectional plane is perpendicular with
respect to the circumferential direction of the tube. An
example according to the tool Embodiment 1 is here
illustrated. The recognizable asymmetry of the structure
is caused by unavoidable tolerances in tool dimensions
and starting-material dimensions.

[0041]   Figure 9 illustrates a comparison of the
performance characteristics of two finned tubes during
shellside boiling of the refrigerant HFC-134a. One of
the tubes has been designed with re-entrant secondary
grooves at the base of the groove. Illustrated is the
heat transfer coefficient for shellside boiling as a
function of the heat flux. The equilibrium temperature
is hereby 14.5°C. It will be recognized that a
performance advantage is achieved utilizing the re-
entrant secondary grooves at the base of the groove,

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which advantage is over 30% during small heat fluxes, and approximately 20% during large heat fluxes.

[0042]   Structures with re-entrant secondary grooves at the base of the groove are also suggested in EP 0 522 985. However, the structure is oriented on the inside of a tube. In order to guarantee the mechanical stability of such tubes in particular when expanding the tubes, the secondary grooves must be designed as flat as possible. This is achieved by the acute-angled geometry of the secondary grooves described in EP 0 522 985. Usually a higher pressure exists inside the tube during the tubeside evaporation of refrigerants than on the outside of the tube. An increased mechanical load on the wall of the tube starts with an internal pressure load from the acute-angled edges of the secondary grooves due to the stress concentration. This must be compensated for by a thicker tube wall. This added safety in the tube wall results, however, in an increased usages of material and thus in increased costs.

[0043]   However, no weakening of the tube wall 18 occurs in the heretofore suggested design of the re-entrant secondary grooves 7 in the area of the base 6 of the primary groove on the outside of the finned tubes since to form the secondary grooves 7 material is used exclusively from the area of the fin flanks 5 and possibly from the radiused portion 13 above the base 6 of the groove.